MEDICAL RESEARCH LABORATORY

U. S. Naval Submarine Base
New London

Volume 9 1950 pp. 291-300

STUDIES IN SHORT DURATION AUDITORY FATIGUE

II. THE EFFECT OF THE DURATION OF THE STIMULATING TONE

III. THE EFFECT OF THE INTERVAL BETWEEN STIMULI

by
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Medical Research Laboratory Report No. 168
BuMed Project NM 003 041.34.02

APPROVED: T. L. Willmon, Captain (MC) USN,OinC, 8 Dec 1950

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Reference may be made to this report as follows: J. D. Harris, Studies in Short Duration Auditory Fatigue, II. The Effect of the Duration of the Stimulating Tone, III. The Effect of the Interval Between Stimuli, MRL Report No. 168, 9, pp. 291-300, 1950.

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OPERATIONAL SIGNIFICANCE

If a repetitive signal is no louder than average speech (50-70 db) it may last anywhere from 0.1 to 10.0 seconds without increasing the auditory fatigue induced by a single signal. At somewhat louder levels, the signal cannot be longer than 5.0 seconds without constantly accumulating more and more fatigue. This fatigue is, however, transitory. All after-effects of a moderately loud tone of the above durations disappear in about one-third of a second. After relatively short tones, and for something less than non-injurious loudness the ear may be trusted to make an adaptation within 0.1 second to the level of stimulation, and to return to its most acute state within less than a second, a recovery in sharp contrast to the slow processes of light adaptation and dark-adaptation of the eye.

ABSTRACT

This series of two experiments investigated the auditory fatigue caused by pure tones up to 70 db sensation level and .1 to 10 seconds in duration, and charted the very quick recovery from these relatively mild stimuli. No cumulative fatigue effects were found up to 5 seconds of stimulation, and only a slight cumulative effect between 5 and 10 seconds at the louder levels. The fatigue occasioned by such tones is transitory, disappearing within a half-second or less. The course of its disappearance is exponential or nearly so for all stimuli used.

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INTRODUCTION

The use of very short intervals of time for the investigation of auditory fatigue has proved extremely fruitful since Goran de Mare first utilized the principal in 1939. In the more usual method of investigation, it has been necessary for the experimenter to stimulate the ear for relatively long periods of time with a stimulus of considerable intensity. Following this stimulation, the return to a normal state of hearing acuity was studied by series of repeated audiograms. Some of the durations and intensities necessarily used in these studies were such that the ear sometimes required many days or weeks for complete recovery. It is apparent that under these conditions the collecting of data is rather time-consuming. These long durations and high intensities, however, were thought necessary, since if milder stimuli were used no fatigue could be discovered; it was indeed a question until quite recently whether the ear actually did suffer any fatigue at all. It occurred to de Mare, however, that one of the reasons for this lack of fatigue was that the ear adapted very quickly, and very quickly returned to normal after the cessation of stimulation; and that if he wished to study fatigue following milder stimulation, he would have to test very soon after the sensation.

The topic of short duration auditory fatigue has been made the subject of papers by Luscher and Zwislocki, of a paper by Gardner, and of a paper by Munson and Gardner. The phenomenon has been given a significance in the field of individual differences by de Mare, in the field of clinical otology by Gardner, it has been used by a series of assumptions to define the loudness pattern on the basilar membrane occasioned by a pure tone by Munson and Gardner, and it has been studied for its own theoretical interests by Luscher and Zwislocki.

The phenomenon is of interest to this laboratory for both practical and theoretical reasons. Since periods of stimulation are so short (usually less than a second) and the period of return to a normal state of acuity occupies usually less than a second, it is possible to stimulate an ear many times in the course of an hour. Using this technique then it may be possible to predict individuals who will suffer more long lasting, perhaps even permanent, damage from loud sounds, and it may be possible that the clinical observations of Gardner may be confirmed and extended; on the theoretical side, each of the several parameters involved in the experimental paradigm are of almost equal interest, one to the other. For example, one may interest oneself in the duration of the first, or stimulating tone, as well as the frequency and intensity; or one's interest may be in the period of time necessary before complete recovery to an auditory stimulus; or one may be interested in the difference in frequency between two tones. Other parameters include the complexity of the two tones and of the frequency difference between them.

The two sections of this paper are concerned first with the effect of the duration of the first or the stimulating tone, and second with the effect of the interval of silence between the stimulating and the test tones. It would logically be expected that as the stimulating tone continues, more and more of fatigue would be accumulated. Secondly, it would logically be expected that as the interval of silence increased between the fatiguing and the test tones, fatigue would decline as a function of time and as a function of the intensity of the stimulating tone. The purpose of this paper is to provide quantitative data on these two hypotheses.

APPARATUS

The apparatus used consisted essentially of two Western Electric 6B Audiometers, which controlled the intensity and frequency of the fatiguing and the test tones. Their outputs were led directly to the subject's headphones, a Permoflux PDR-8 type. The durations of the tones and of the interval of silence between them were controlled by a Potter Instrument Co. Electronic Counter, capable of controlling three successive time sequences each from one millisecond to 10 seconds, with accuracy considerably better than one millisecond.

PROCEDURE

The experimental procedure is described in detail in the first article of this series. Briefly, an absolute intensive threshold was determined for the first tone, and another independently for the second tone; subsequently another threshold was determined for the second tone, when the first preceded it. The difference in thresholds of the second tone, with and without the preceding fatiguing stimulus, is defined as the amount of fatigue occasioned by the fatiguing tone.

The exact conditions (duration and frequency) of the several experiments will be found in the graph at the end of the article.

RESULTS AND DISCUSSION

1. The Effect of the Duration of the First Tone.

In this experiment, the interval of silence was held constant at 20 ms, the duration of the second tone at 30 ms. The duration of the first tone was varied from .1 of a second to 10 seconds. Two conditions were used 1. a half an octave difference, and 2. a full octave difference between the two tones. Figure 1 shows for the half octave difference and the 500 millisecond first tone duration, the average fatigue for 9 different sensation levels of the first tone. Each point is an average of five independent observations on one subject. The averaged raw data as exemplified in Figure 1, can be recast in another form, as shown in Figures 2 and 3, to present a direct picture of the effect of duration of the first tone. In Figure 2 for the half octave difference, and for five different sensation levels of the first tone from 40 to 80 decibels, it is seen that from .1 of a second up to 5 seconds it is immaterial how long the first tone stimulates. There is a suggestion that at the higher intensities a difference exists between the 5 and the 10 second durations. The case for the full octave difference is shown in Figure 3. Through a sensation level of 70 decibels, no difference can be seen between .1 and 5 seconds, but at higher sensation levels a progressive increase in fatigue is seen with duration of the first tone.

These results do not accord very well with the two previous observations on the point. Gardner states (page 183) that a stimulating tone of 2 seconds was chosen "on the basis of earlier work (unpublished) on normal observers by S. H. Graham in which it was found 'that with an initial impulse of approximately 2 seconds in length the masking of the second impulse is approximately at the knee of a saturation curve' ". In neither of our Figures 2 or 3 is there any suggestion that 2 seconds forms a critical point, except at the full octave data in Figure 3 at the 75 db sensation level. Lüscher and Zwislocki present data showing that at one intensity of the first tone, no difference exists between durations of .4 seconds and 2 seconds, (page 135), and this indeed accords with our data. However, their assumption that fatigue falls off rather sharply with durations of less than about .2 of a second is evidently in some slight error. The data in Figures 2 and 3 are rather surprising, indicating as they do that for moderately loud tones up to 10 seconds (and for weaker tones perhaps indefinitely) the ear suffers an appreciable diminution of acuity, up to 25 or 30 decibels, and yet during all this time no accumulation of the catabolic processes occurring during stimulation takes place. This fact seems to lend point to Lüscher and Zwislocki's insistence that the phenomenon is not in all ways similar to what is usually thought of as physiological fatigue, but is more closely related to the concept of the adaptation of a sense organ to continuous stimuli. However, as Figure 3 shows, at the 85 decibel sensation level, fatigue is increasing rather rapidly with duration of the first tone, and it seems to the writer reasonable to assume that no qualitative difference will be discovered between this sort of phenomenon and the classical picture of auditory fatigue.

II. The course of the return to normal acuity after stimulation.

In this experiment, in order to obtain the maximum fatigue, both frequencies were made the same. The fatiguing tone was always 400 milliseconds, the test tone always 50 milliseconds in duration. The interval of silence was varied from 20 to 300 ms. Figure 4 shows the data for 3000 cycles. Here can be seen the way fatigue rises with sensation level of the first tone, at each of six inter-stimulus interval. A difference will be observed between the slopes of

these curves and that in Figure 1. In the earlier figure, no fatigue occurred until the first tone was about 40 db sensation level, whereas in Figure 4 where both tones of the same frequency, at the same 20 ms interval of silence, fatigue begins when the first tone is only slightly above 10 db sensation level. This difference as to the intensity of stimulation which first brings on fatigue is readily explained however by the frequencies involved. A more perplexing difference occurs, in that the data of Figure 4 seems to indicate a double slope. Nothing of the sort occurs in the data of Lüscher and Zwislocki (Figure 4, page 433), but an even more perplexing shape appears in the data of Gardner (Figure 6, page 184), and of Munson and Gardner (Figures 7, 9, and 10, pages 180-181), where what the Bell Telephone workers term a "saturation effect" occurs, such that as the first tone is raised in intensity from about 40 or 50 to perhaps 80 db sensation level, relatively little additional fatigue is occasioned. The data of Munson and Gardner were gathered at an inter-stimulus interval of about .1 and about .2 seconds. They state that "tests at shorter delayed times indicate that saturation becomes less noticeable as this factor decreases until a zero time (i.e. for simultaneous masking) it is difficult to detect or entirely absent". However, it is seen in Figure 4 that the double slope feature of our data is maintained at all inter-stimulus intervals used.

It is clear that data such as in Figure 4 may be recast in another form to show the course of decline of fatigue. Figure 5, for 500 cycles, and Figure 6, for 8000 cycles, show two further sets of data. The figures are interpreted as follows: at 500 cycles, when the first tone is of 70 db sensation level, fatigue has reached a level of about 57 db after 20 ms; has declined to about 30 db after 120 seconds; and has reached a zero value at 260 ms. The differences between the sets of data in Figure 4, 5, and 6 may in part be attributed to the differential effect of frequency at constant sensation level, as described in our earlier paper, and in part perhaps to the status of the particular ear at the several frequencies.

The exact slope of the decline of fatigue is a matter of considerable interest. Lüscher and Zwislocki have published the data for one frequency using six sensation levels of the first tone. Figures 5 and 6 confirm their results in that at the lower sensation levels the curves follow a course of initial negative acceleration, while at the medium and louder levels the curves are straight lines. Since the ordinate is a logarithmic scale, this means that the return follows an exponential function. In order to check the un-

iversality of this point, and to get an idea of individual differences, the decline of fatigue for a 50 sensation level tone of 2000 cps was determined for eight subjects. The average fatigue at each inter-stimulus interval, and the standard deviation, are shown in Figure 7. It is clear that the best fitting curve is a straight line for this particular sensation level, and that there is relatively slight individual differences in the course of the disappearance of fatigue. These eight subjects all had essentially normal hearing; it remains to be determined whether the decline of fatigue takes this same form in cases with various types of deafness.

SUMMARY AND CONCLUSIONS

The technique of studying auditory fatigue using brief, weak tones has proved very fruitful, since the ear's return to normal is so quick that a great deal of information can be gathered in a short time. The two studies reported in this paper concern the effect of two variables, first, the duration of the stimulation, and second, the course of the recovery from fatigue.

Two Western Electric audiometers were used to produce Tone A, the fatiguing stimulus, and Tone B, the test tone used to determine the momentary status of the threshold. In the first study, Tone A was varied from .1 to 10 seconds in duration, at each of 5 sensation levels up to 80 db, while Tone B of 30 milliseconds duration was introduced 20 milliseconds after the termination of Tone A. The rather surprising fact appeared that for the case of a half-octave difference between Tones A and B, no cumulative effect of stimulation appeared until more than 5 seconds had elapsed, and then only for the louder levels -- and this even though the fatigue occasioned by such stimulation was as high as 40 db. Evidently the ear very quickly sets up a state of adaptation which can maintain a steady equilibrium for considerable periods of time.

In the second study Tone A was 400 ms, Tone B 50 ms, the interval of silence between them being varied from 50 to 300 ms. At the frequencies 500, 2000, and 8000, recovery from fatigue is complete within less than one-third second when Tone A is of 70 db sensation level. For weaker stimuli, recovery is proportionately quicker. At about 50 db SL and louder, the disappearance of fatigue follows an exponential course; at weaker levels, the recovery exhibits an initial negative acceleration. This recovery process is quite dif-

ferent from the decay of sensation when a tone ceases, and is also quite different from the damping of the sound conduction apparatus, both of these processes being complete by about 20-30 milliseconds.

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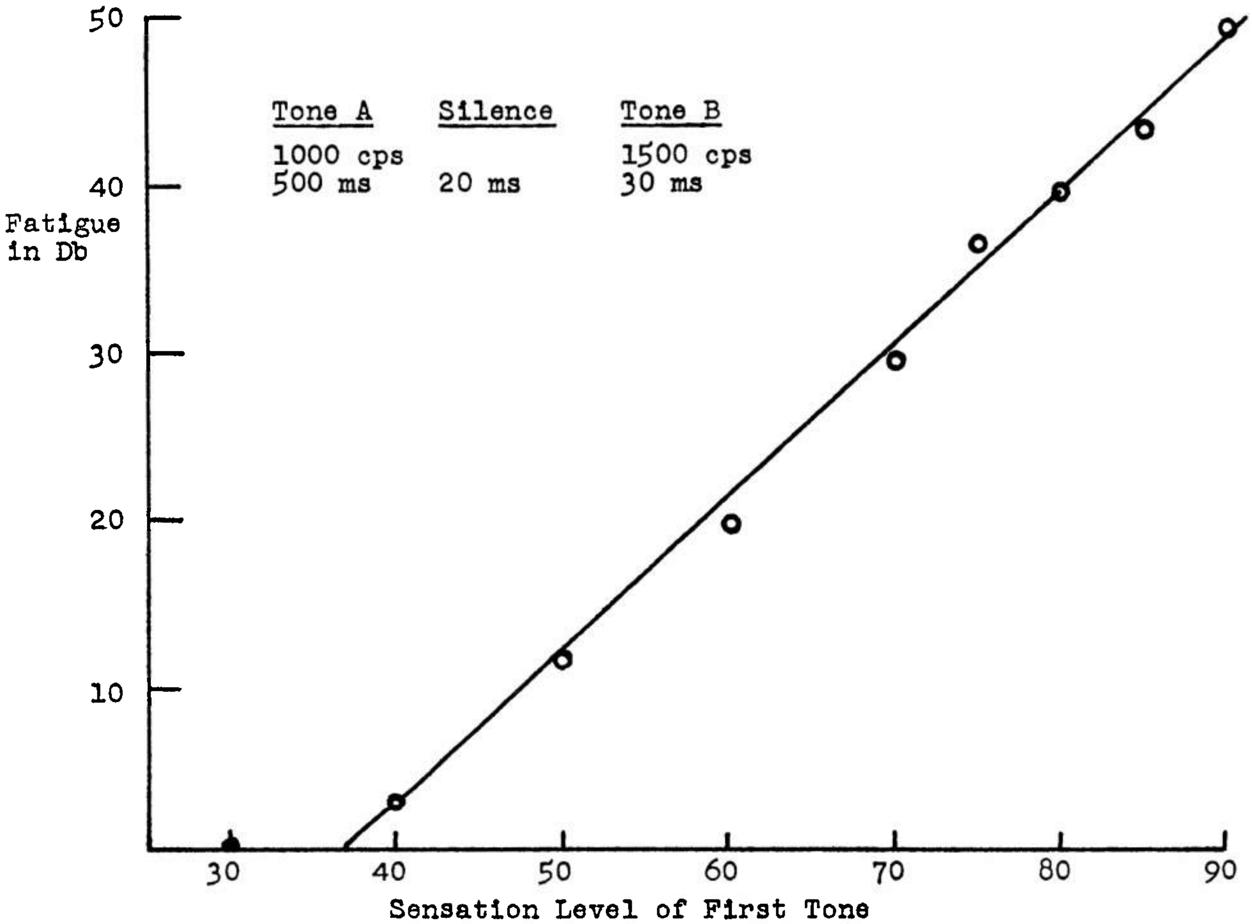
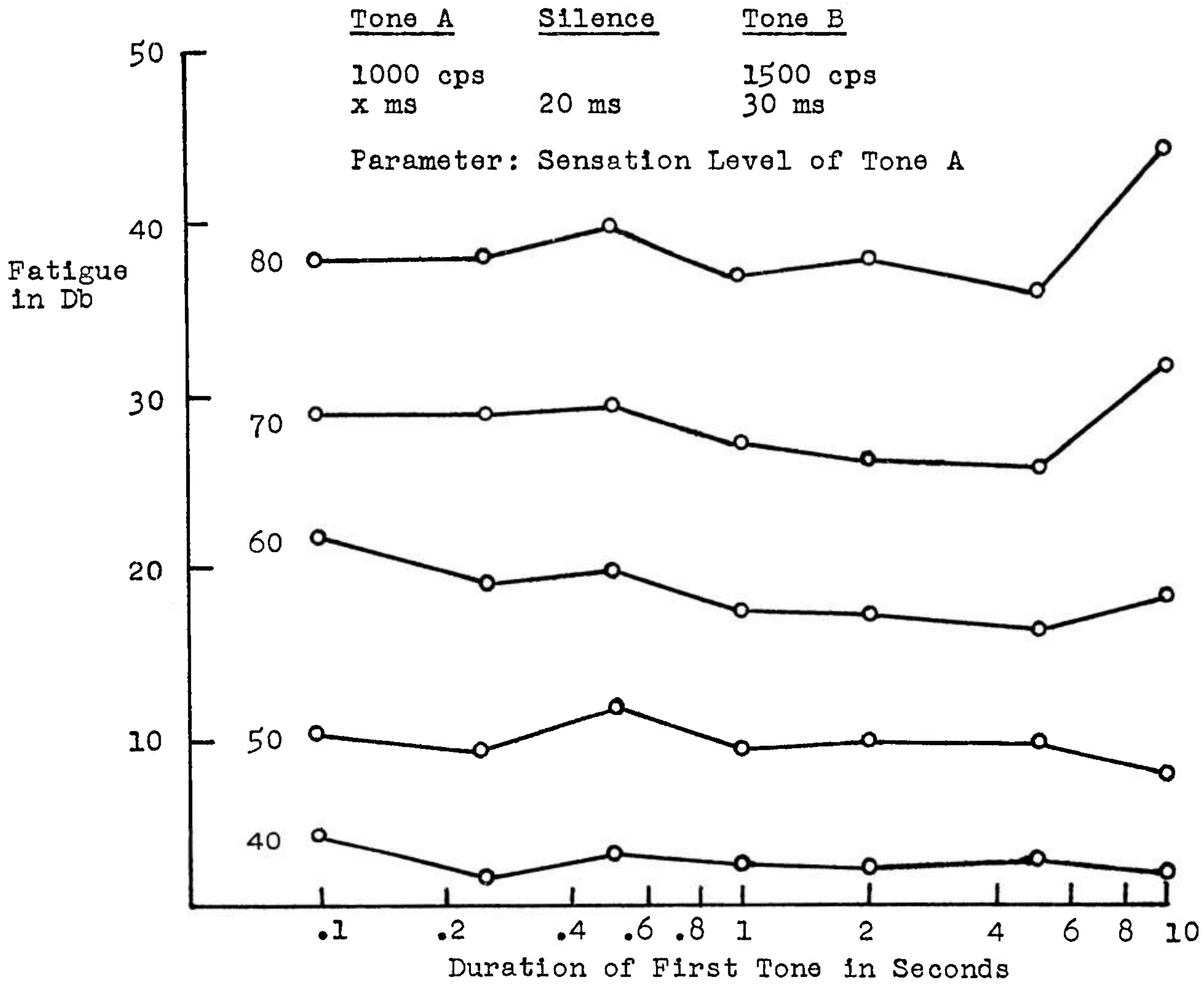


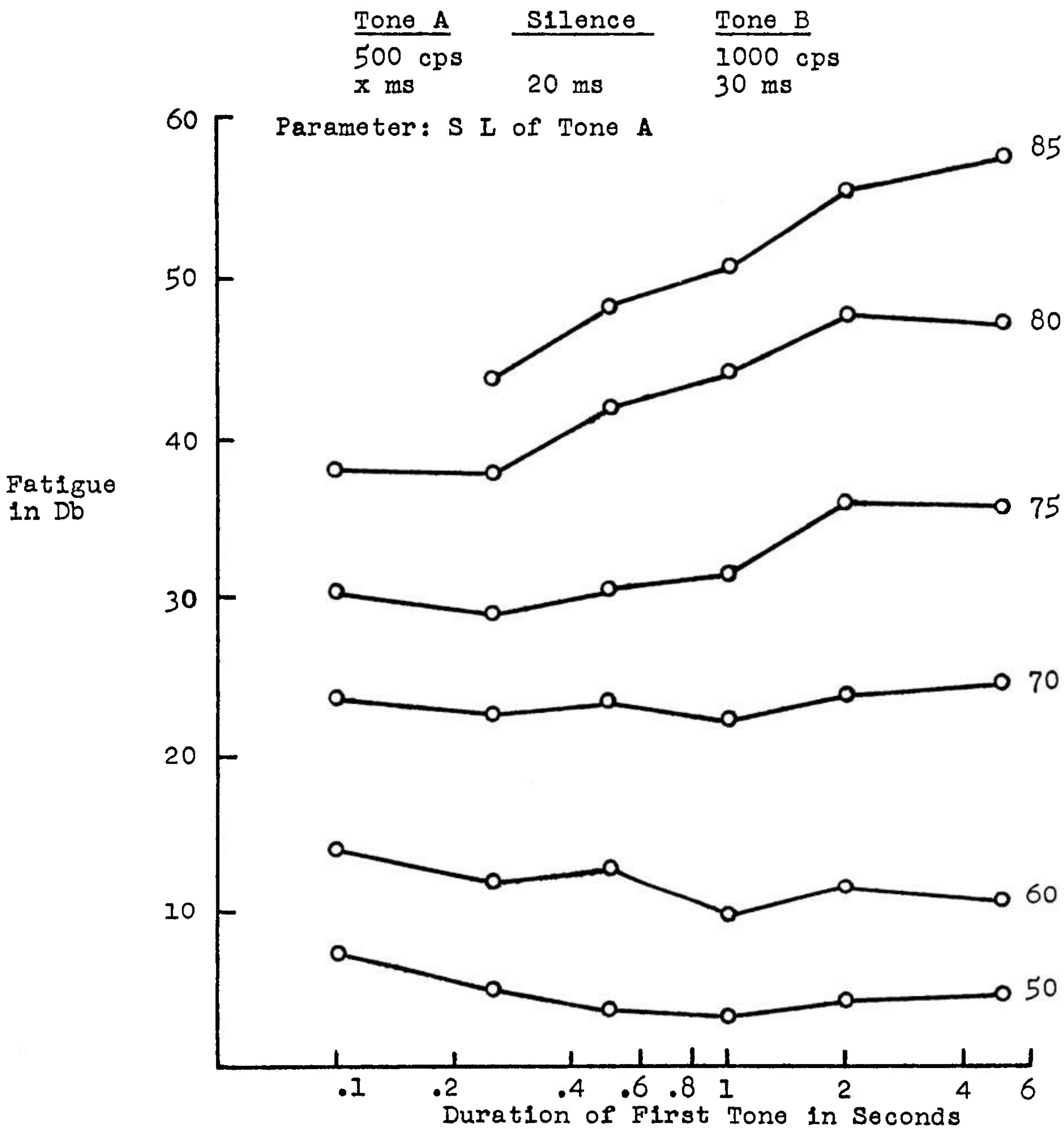
Relation Between Fatigue and Intensity of Stimulus

Fig. 1



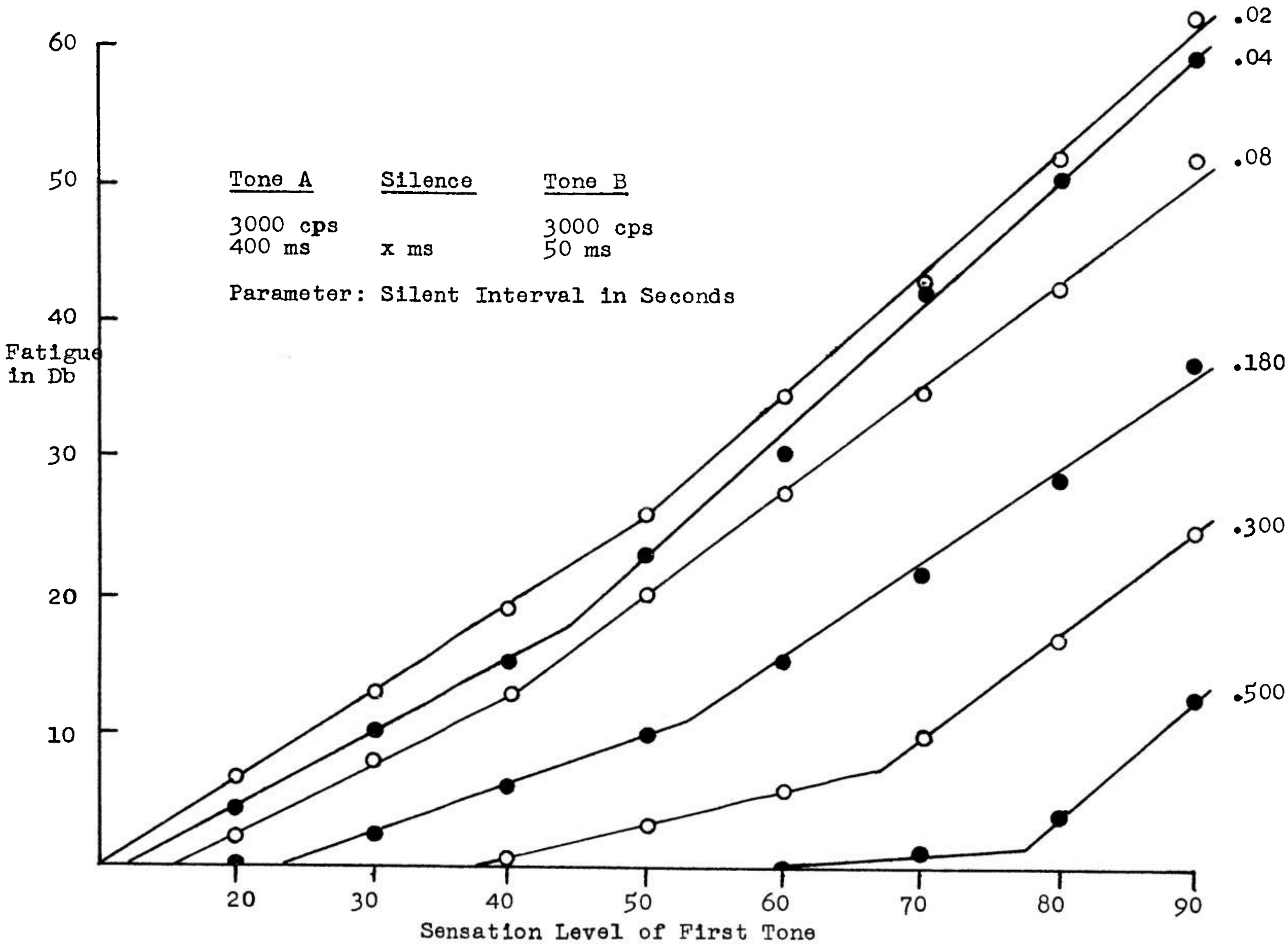
Effect of Duration of Stimulation

Fig. 2



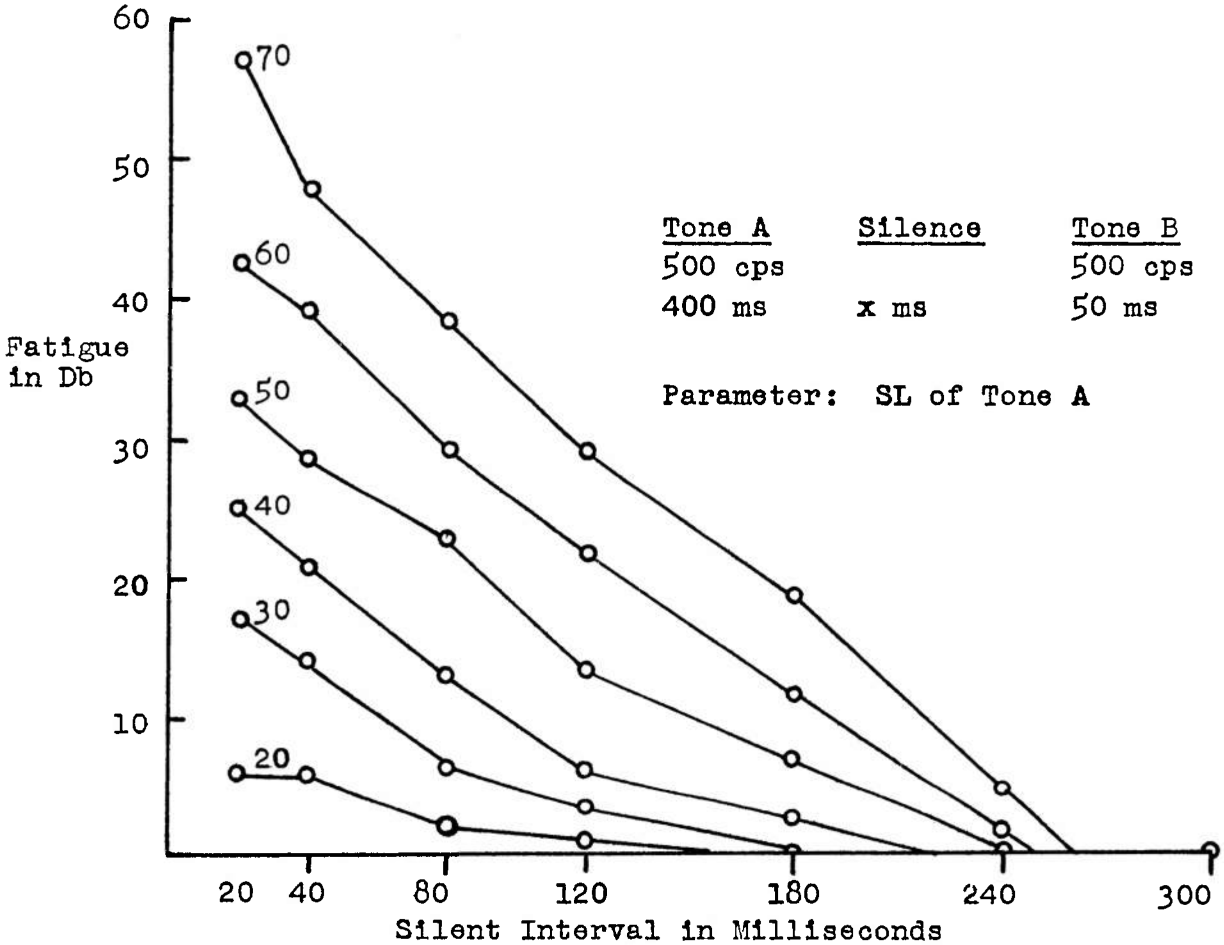
Effect of Duration of Stimulation

Fig. 3



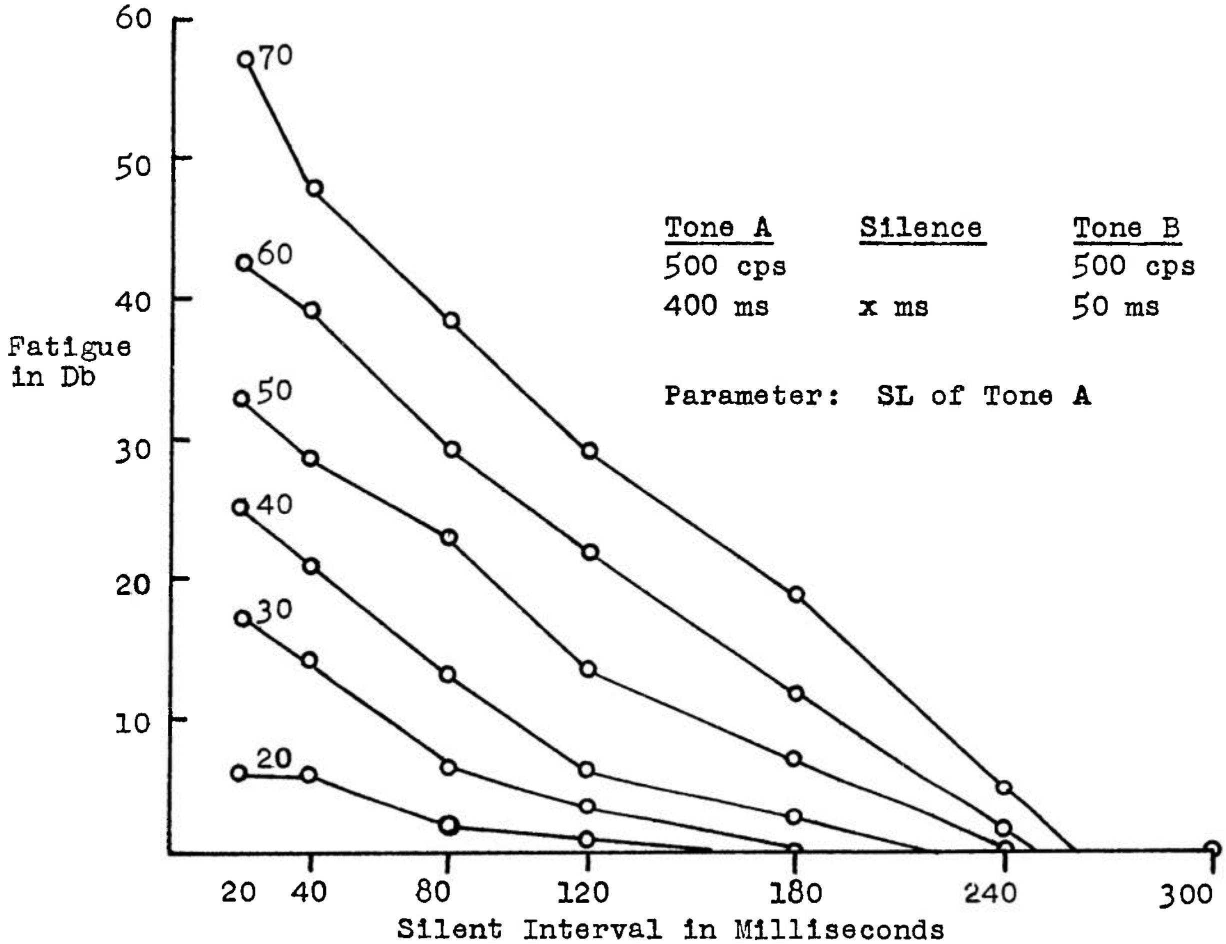
Tone A
3000 cps
400 ms
Silence
x ms
Tone B
3000 cps
50 ms
Parameter: Silent Interval in Seconds
Fatigue in Db
60
50
40
30
20
10
20
30
40
50
60
70
80
90
Sensation Level of First Tone
.02
.04
.08
.180
.300
.500

Fig. 4



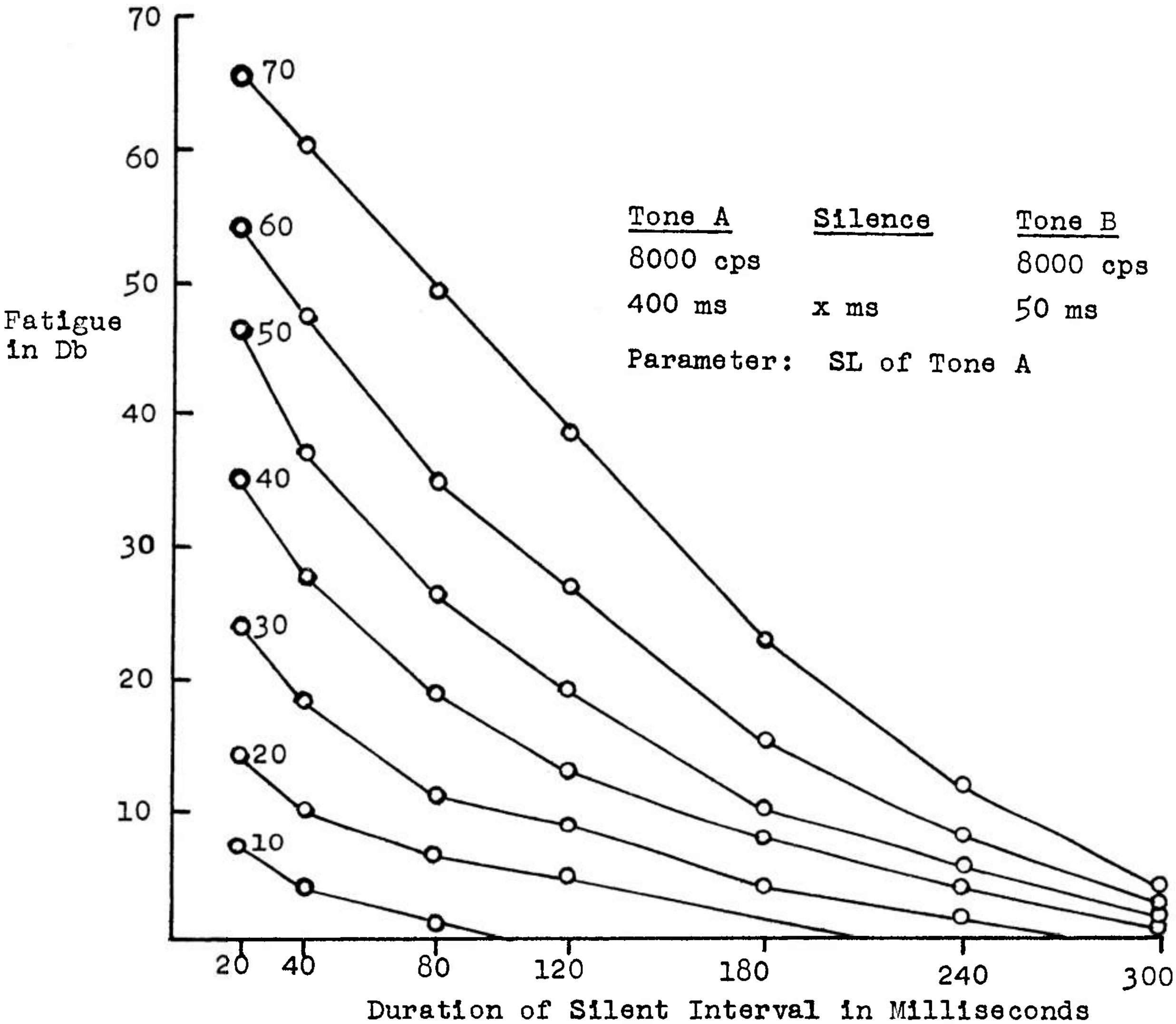
Course of Recovery from Fatigue

Fig. 5



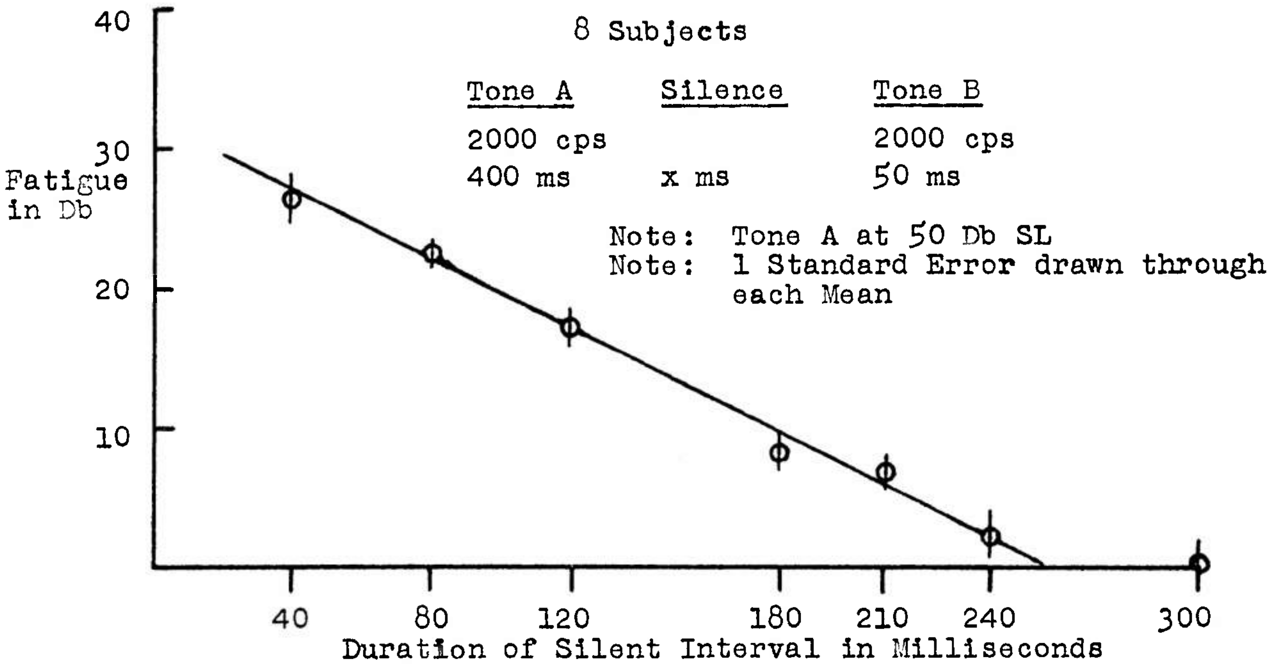
Course of Recovery from Fatigue

Fig. 5



Course of Recovery from Fatigue

Fig. 6



Shows Average Course of Recovery from Fatigue

Fig. 7